The new experiment on P and T violation with ultra-cold neutrons: Electric field diagnostics via Kerr effect in liquid helium

A. O. Sushkov[1,2,*] V. V. Yashchuk[1,†] D. Budker[1,3,‡] and S. K. Lamoreaux[§]
[1] *Department of Physics, University of California at Berkeley, Berkeley, California 94720-7300*
[2] *Los Alamos National Laboratory, Los Alamos, NM 87545*
[3] *Nuclear Science Division, Lawrence Berkeley National Laboratory, Berkeley, California 94720*

A new experiment searching for the P- and T-violating electric dipole moment (EDM) of the neutron, d_n, that will be based at LANL is currently being developed [1]. The possible existence of a neutron EDM of a measurable magnitude is of fundamental importance, as it directly implies physics beyond the Standard Model and may provide clues to an explanation of the baryon asymmetry of the Universe [2]. The goal is a two orders of magnitude improvement of the sensitivity over the present limit of $|d_n| < 0.63 \times 10^{-25}$ e·cm [3].

Briefly, the experiment involves forming a three-component fluid of ultra-cold neutrons and polarized ^{3}He atoms in a bath of superfluid ^{4}He at a temperature of 300 mK. The ultra-cold neutrons are loaded into the neutron trap by downscattering of 8.9 $\AA$ neutrons in the superfluid ^{4}He phonon-recoil process [4]. Placed in an external magnetic field **B**, both the neutron and the ^{3}He magnetic moments precess in the plane perpendicular to **B**. When a strong electric field **E** parallel or antiparallel to **B** is applied, the precession frequency of the neutron dipole moment changes if the EDM is non-zero. The measurement of the neutron EDM comes from a precision measurement of the difference in the precession frequencies of the neutrons and the ^{3}He atoms (which have essentially zero EDM) as **E** is reversed. The ^{3}He atoms serve three functions in this experiment: they polarize the neutrons, detect the difference in precession frequencies of neutrons and ^{3}He, and serve as a co-magnetometer measuring *in situ* the magnetic field **B**. For more details see [1].

The magnitude of the electric field is ~ 50 kV/cm, and it has to be uniform and stable to 1%. Monitoring the electric field and its reversals inside the liquid helium bath is a daunting task, especially since the leakage currents have to be kept to the level of nano-amperes. We proposed to use the Kerr effect in liquid helium to accomplish this task. Under the applied electric field **E** the initially isotropic liquid helium acquires linear birefringence, proportional to E^2. For input light linearly polarized at 45° to the direction of the electric field, the ellipticity of the light polarization at the output is $\varepsilon = (\pi l/\lambda) K_{LHe} E^2$, where l is the path length and K_{LHe} is the Kerr constant of the liquid helium, λ is the wavelength of the light. By measuring ε we plan to monitor both the spatial and the temporal variations of the electric field.

To our knowledge, the Kerr constant K_{LHe} of liquid helium has not been measured. Our calculations in the approximation of non-interacting He atoms, taking into account the 1s, 2s, and 2p levels, lead to the result: $K_{LHe} = 1.7 \times 10^{-20}$ (cm/V)^2. A direct measurement of K_{LHe} has been set up in our laboratory at Berkeley. The apparatus includes a pumped ^{4}He cryostat with optical-access, which achieves temperatures down to 1.3 K. We apply electric fields up to 100 kV/cm to a pair of electrodes in the cryostat sample space. The Kerr-induced ellipticity is determined with a modulation polarimeter incorporating a 780 nm diode laser and two polarizers with the cryostat and a photo-elastic modulator (PEM) between them. Lock-in detection of the transmitted light intensity at the PEM frequency of 50.2 kHz measures the ellipticity of the light passing through the cryostat with sensitivity $\sim 10^{-7}$ rad.

We have tested the apparatus by measuring the Kerr constant of liquid nitrogen: $K_{LN2} = (4.2 \pm 0.1) \times 10^{-18}$ (cm/V)^2, which agrees with the previously published results [5]. Preliminary results for K_{LHe} have also been obtained (which are in agreement with our theoretical estimate). We are presently measuring K_{LHe} as a function of temperature. Here the behavior of the Kerr constant near the superfluid transition is of particular interest.

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* Electronic address: `alex000@socrates.berkeley.edu`
† Electronic address: `yashchuk@socrates.berkeley.edu`
‡ Electronic address: `budker@socrates.berkeley.edu`
§ Electronic address: `lamore@lanl.gov`

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